Summary Report

LUNAR SURVEY PROBE

SENSOR STUDY

MR 1272-2

Prepared for

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Manned Spacecraft Center
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Prepared by

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I. INTRODUCTION

This report summarizes the work done by the MRD Division of General American Transportation Corporation on Contract NAS 9-3731 "Lunar Survey Probe Sensor Study". A detailed discussion of the scope of the study, and its findings, results, and recommendations is presented in a separate document MR 1272-1 Final Report dated July 1, 1965.

II. STUDY OBJECTIVE

The objective of the program was to determine which parameter measures are feasible for use in the assessment of a lunar surface site's acceptability for a safe LEM landing. The assessment is to be a GO/NO-GO decision.

The study included a parallel examination of a delivery system in sufficient detail to permit a concept freeze.

Following this effort, a conceptual design was carried out and sufficient models, mockups, and tests were made to demonstrate feasibility and assess the degree of correlation of sensor measurement with LEM landing action.

III. RELATIONSHIP TO OTHER NASA EFFORTS

This study specifically relates to Apollo program planning efforts. The particular planning area pertains to the requirements for, and the nature of, lunar reconnaissance missions using probe systems. The probe missions most directly relating to this program would be those designed to furnish information related to the selection of sites for a manned LEM landing on the lunar surface.

IV. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

A. Mission Model

The following mission configuration has been defined as the functional environment within which the Lunar Survey Probe Sensor (LSPS) must operate.

A Lunar Survey Probe (LSP) will be launched from the Apollo orbital vehicle and transferred to a landing orbit terminating at a predetermined lunar surface site. Just prior to impact, the LSP will eject a number of LSPS units while hovering at a nominal release altitude. The units will then free fall from the release point and come to rest on the lunar surface at their individual landing points. This will be accomplished with a controlled amount of horizontal dispersion. They will each perform a test of surface load bearing strength and then report the acceptability of the site to the orbiting spacecraft. Analysis of the reply sample will then be used in assessing the acceptability of the site area.

B. Principal Assumptions

The basic assumptions and ground rules limiting and defining the study scope and concept configuration are the following:

1. A LEM landing is defined as being safe when none of the four LEM landing pads penetrates more than 12 inches into the lunar surface when maximum impact velocity is 10 fps. Under a deceleration limited to 4 g (earth), the dynamic loading pressure of a LEM pad is 12 psi.
2. The basic measurement technique used shall result in a GO/NO-GO decision. The resultant LSPS message is thus to be limited to that form.
3. The LSPS messages are to be communicated to a spacecraft orbiting the moon at a nominal altitude of 80 nautical miles and having an orbit velocity of 5000 fps.
4. As a design goal, each LSPS unit is to have a weight limit of 10 pounds (earth).

C. Method of Approach

The program was separated into the two broad areas of concept evaluation and conceptual design.

1. Concept Evaluation. This area consisted of a detailed examination of the following:

1.1 An investigation and evaluation of measurement techniques was aimed at finding the physical parameters which are most useful to the defined test mission. This effort included theoretical and experimental investigations of soil mechanics and dynamic penetration behavior in a range of soil models. The predictions derived from the theory were tested experimentally. The results of this analysis were then used to recommend a particular measurement technique.

1.2 An investigation and evaluation was made of techniques for communicating a test result message from the lunar surface to an orbiting spacecraft. The optical and radio frequency regions of the electromagnetic energy spectrum were both evaluated for their capabilities and limitations in communicating the LSPS messages. Individual characteristics of specific promising system techniques were evaluated. The results of this study were then employed in recommending a specific communication system configuration.

1.3 Various techniques were examined for delivering an LSPS unit to the lunar surface following ejection and free fall from the LSP. Both soft (rocket thrust retardation) and hard (crushable shroud and inflated bag) impact limiting techniques were evaluated for their effectiveness and compatability to the functional and physical requirements of the system.

2. Conceptual Design. The findings of the evaluation study formed input requirements to a conceptual design in which basic techniques and components were described for implementing an overall system function, structure, and package design.

A number of demonstration models were fabricated to prove the feasibility of some of the basic function and package requirements. Also, 10 dimensional mockups were constructed of the LSPS package in stowed condition. These are to be used in planning provision in the LSP for payload stowage and jettisoning.

V. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The following is a summary of the results and recommendations of the evaluation study and concept design.

A. Measurement Techniques

1. Results

This area of the study was initially directed toward examining the relative merits of direct versus indirect soil measurement parameters. The results of this examination indicated the desirability of using direct soil measurement parameters. In particular, the requirement to relate any measurement to the penetration behavior of a LEM pad led to the decision that penetration into the soil was the most useful and reliable parameter.

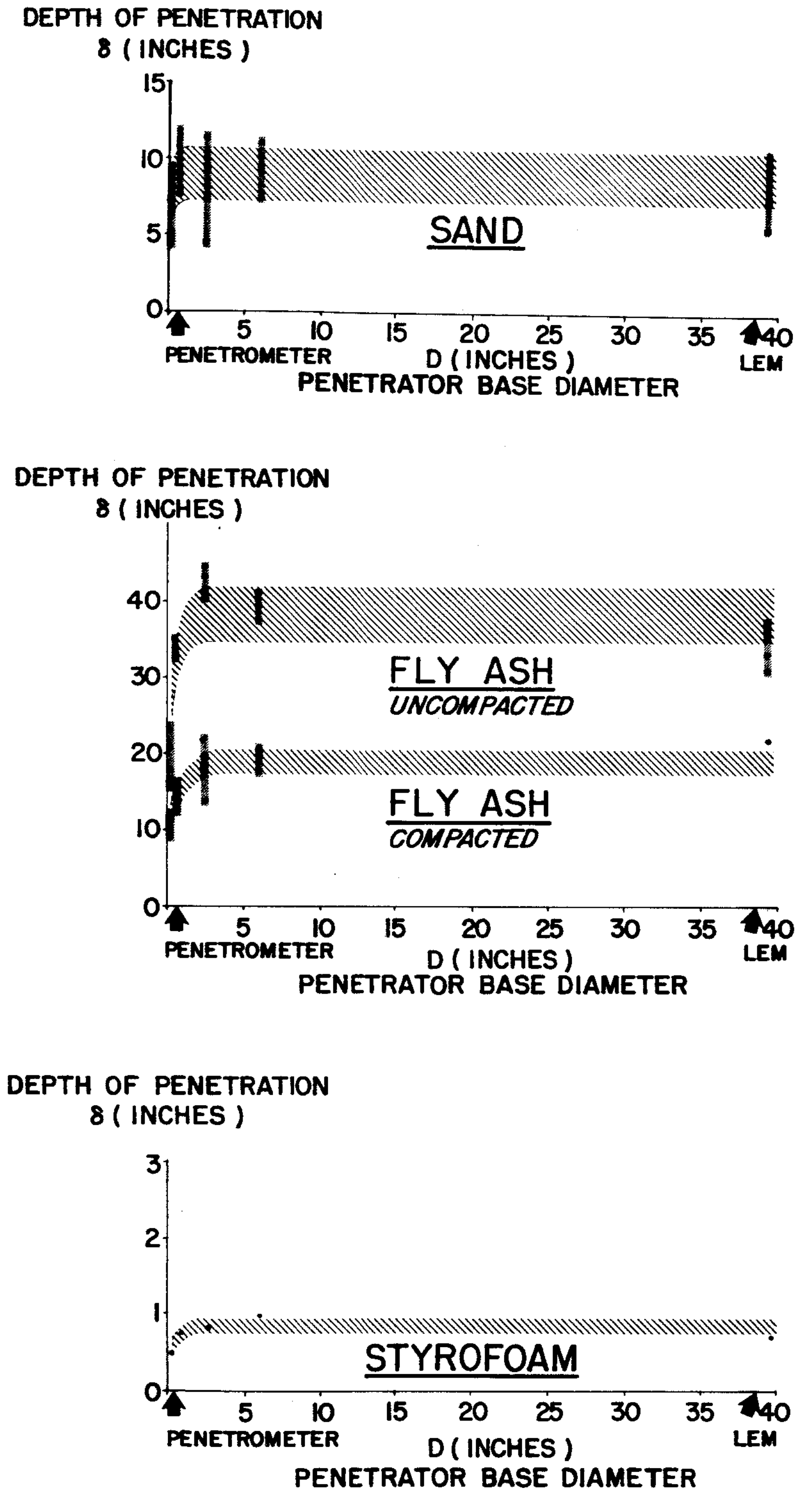
A variety of idealized penetrometer models were considered by studying various combinations of the basic variables of impact velocity, mass, and radius. These basic variables and functional combinations of them were examined with respect to analytic models of the soil failure mechanism in various soil systems. Mathematical models of soil failure were examined for those functional relations of the above parameters which would afford a favorable scaling relationship from a physically small penetrometer element to the full size LEM pad. It was found that in a satisfactorily wide range of soil models, the best penetrometer configuration was the following:

The penetrometer should retain the mass per unit area (areal density) of the LEM. Also, the maximum impact velocity of the LEM should be retained. The retention of areal density and velocity automatically provides a simulation of kinetic energy and momentum per unit area. It was further found that reducing the diameter of the shank of the penetrator element from that of the base improved the range of penetrometer base diameter over which a simple scaling relation would hold in granular material.

It was found, both by analytic prediction and experiment, that a small penetrator element could reliably predict the penetration threshold of the full size LEM pad with a high degree of confidence. Tests were made with a series of penetrometers in fly ash, representing a granular medium, and styrofoam, representing a crushable medium. The penetrometers ranged from 1/8 inch to six inches in diameter and all possessed the same areal density of 0.039 slugs/in^2. These results showed an almost unity scaling factor for the penetrometer down to approximately one-inch diameter. These tests were subsequently extended to duplicate the LEM pad areal density and to include a full scale representation of a LEM pad. Five penetrometers were used having diameters at the base of 1/8 inch, 3/4 inch, 2-1/2 inch, 6 inches, and 1 meter cr 39.4 inches. All had an areal density of 0.093 slugs per square inch. Their earth weights ranged from 0.036 lbs. to approximately 3600 lbs. for the full sized LEM model. Soil models used were sand, fly ash, and styrofoam. Again the test results showed a simple scaling relationship between a small penetrometer and the largest. An idealized representation of the test results are shown in Figure 1.

2. Recommendations

From the results of the study it was recommended that the measurement parameter be penetration obtained by propelling a penetrometer element to impact the lunar surface at 10 ft. per second. The recommended penetrometer base diameter is 0.75 inches which corresponds to a weight of 1.3 lbs. (earth) for the normal LEM areal density of 0.093 slugs per square inch.



EXPERIMENTAL SCALING BEHAVIOR

IMPACT VELOCITY = 10 fps
MASS PER UNIT AREA = .093 slugs / in²

Figure 1

It is further recommended that the GO/NO-GO criteria be based on detecting a penetration threshold of 10 inches for the recommended penetrometer to provide a high degree of reliability on the decision over a wide range of soil characteristics.

B. Communications Techniques

1. Results

An evaluation of communications in the optical region versus the radio-frequency region resulted in the finding that r-f techniques were to be preferred due to the large noise background energy in the optical region in lunar day conditions.

An examination of wave length factors showed that antenna dimensions and transmitter power requirements in the VHF region offered advantages over the HF and UHF regions. Further examination of system configurations showed that double side band amplitude modulation was the simplest modulation approach.

Since the information is a simple two state message, continuous tones representing the GO and NO-GO messages were found to be a desirable format. It was also found that channel identification by assignment of carrier frequency is feasible for the system concept.

2. Recommendations

The recommended communication technique is as follows:

It is recommended that the LSPS communication system operate in the radio frequency region. Each group of sensor carrier frequencies should be located in the region near 300 megacycles per second frequency.

Double side band amplitude modulation should be used and the message format shall consist of two unique tones assigned the message values of GO and NO-GO respectively.

It is further recommended that the transmitter be operated cyclically in a 10 percent duty cycle consisting of one second on and nine seconds off to provide an operating life of approximately ten hours.

C. Delivery System

1. Results

A study of various impact limiting techniques indicated that an inflated bag with an essentially inextensible skin was the most compatible technique for use in our system configuration. The method was found to be capable of storing impact energy during compression of the gas volume while offering a low pressure dynamic contact with the soil, thus minimizing disturbance of the lunar surface. The inflated bag also offered, by choosing the proper envelope shape, the desired features of controlled orientation and positioning of the penetrometer element, the establishment of a measurement datum reference plane, and such necessary auxiliary functions as erection of communication antennae.

An examination of the post impact dynamics of such a package show that rebound motion results in a requirement for an allowance of time to settle after impact. It is predicted that this time can be held to less than the three minutes allowed when communicating in the first orbit pass.

2. Recommendations

It is recommended that the delivery system be based on the use of an inflated bag. The bag will be a torus in order to provide a stable orientation on coming to rest and the required clear field of view of the lunar surface for the penetrometer element. The operating components of the penetrometer system should be designed to operate bisymmetrically and to be provided with gravity sensors to provide initial information on desired direction of operation, i.e. downward toward the surface.

As a result of the system recommendations to date, the function sequence of the system should be based on a post impact operation of the penetrometer and communication systems starting from a motionless state. Thus the penetration measurement will proceed from a controlled initial condition on relatively undisturbed lunar surface material.

D. Conceptual Design

The mechanical arrangement of a recommended system is shown in Figure 2.

1. Bag, Core and Tank Assembly

The recommended bag dimensions are a major diameter of 75 inches, a minor diameter of 36 inches, and a cylindrical inner core diameter of 3 inches.

The bag has a gas volume of approximately 72 cubic feet and it is recommended that it be filled with helium gas to an initial pressure of 1.28 psi. The peak pressure on impact will be 2.51 psi. The gas required to provide these conditions will have a weight of approximately 0.065 pounds earth.

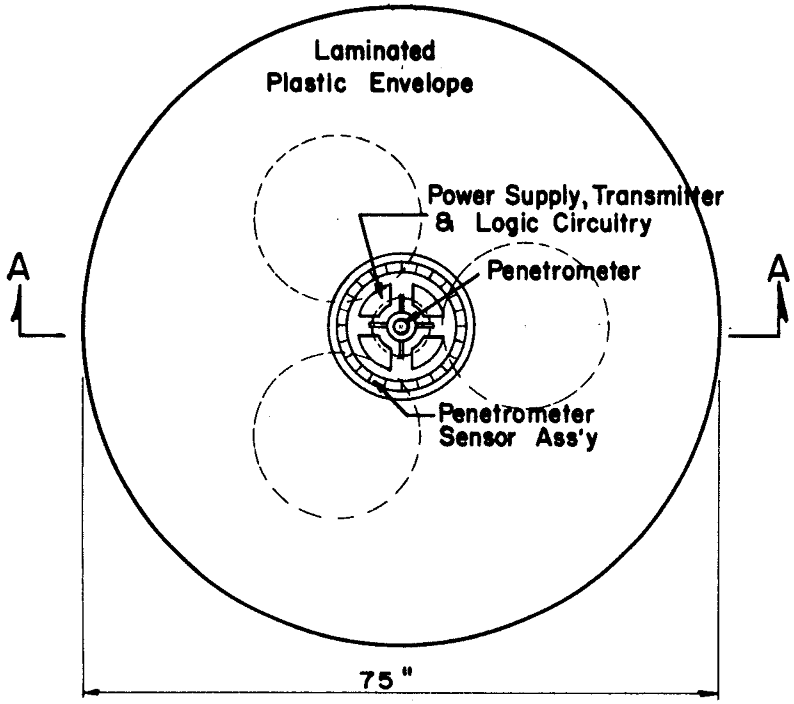
The core experiences the highest stress loads and will be made of laminated epoxy fiberglass. The bag material will be integrally bonded to this core and will be of multiple ply construction tapering to single ply.

Inflatant gas will be stored in a tank wound helically about the core exterior and thus be inside the bag. Also shown are three elastomer skin secondary balloons which are partially inflated at the time of bag erection and provide emergency means to maintain full extension of the bag skin against loss of integrity of the main bag after impact.

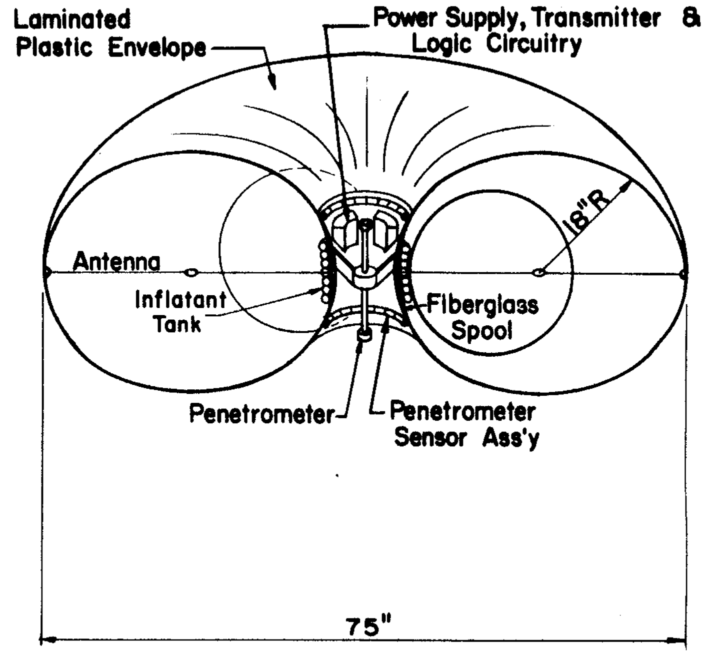
2. Penetrometer Assembly

A high density penetrometer rod will be made using tungsten and providing for the insertion of two cylindric permanent magnets near the end of the rod. The penetrometer rod is provided with two end caps. Each contains an electrically initiated detonating unit used for propelling the rod with a known velocity. The endcaps are assembled to the penetrometer rod with shear pins having a calibrated strength. In use, the proper penetrometer cap (up) will be chosen by a gravity switch and detonated by an electrical signal. The resultant detonation will build up gas pressure within the cartridge piston chamber until the shear strength of the pin is exceeded thus providing a uniform initial propulsion force by "shot start" action. The separated cartridge cap will be ejected upward with a high velocity and its mass reaction will be proportioned to that of the penetrator slug to result in the predetermined impact velocity. The unfired endcap remains on the penetrometer as a penetrating foot of the desired diameter.

Sensor rings are also included as part of the penetrometer assembly and one of these (down) will be released prior to firing the penetrator element. This sensor ring contains a number of magnetic reed switches which sense the passage



PLAN VIEW



SECTION AA

STATIC	
VOLUME	72.3 FT
PRESSURE	1.28 psi
MAX. PRESSURE	2.51 psi

PRELIMINARY WEIGHT ESTIMATE	
Envelope & Core	2.6 lbs.
Gas System	1.5 "
Penetrometer System	2.2 "
Power & Electronics	2.1 "
Structural System	0.5 "
Canister	1.0 "
TOTAL	9.9 lbs.

LSPS SYSTEM LAYOUT

Figure 2

of the magnets in the penetrometer rod. A logic circuit determines whether one or both ends of the penetrometer element passed through the sensor ring. If the test situation is defined as GO, the rod will penetrate less than its ten inch separation between magnets. If the penetrometer enters the surface more than the ten inch separation between its two magnets, the sensor ring will have been actuated a second time and this will be interpreted by logic circuits as a NO-GO situation.

It should be noted that the rod propulsion principle is essentially recoilless with respect to the bag and core assembly. Thus rod propulsion does not disturb the structure to which the sensor ring is attached.

3. Control System

A control system is provided which initiates all required actions following jettisoning of the stowed LSPS system from the LSP until the final testing function and subsequent message transmission to the CSM. It includes provision for sensing cessation of motion.

4. Communication System

Figure 3 shows a simplified block diagram of the transmitter systems representing a group of LSPS units and the associated receiver capable of identifying the individual replies and interpreting their message.

5. Operating Sequence

The system described above is intended to operate as follows: The stowed LSPS system in its folded state and stowing container is jettisoned from the LSP.

Separation of the LSPS from the LSP removes a lanyard pin which opens and jettisons the protective shroud around the folded bag and stowed system and initiating the bag inflation process.

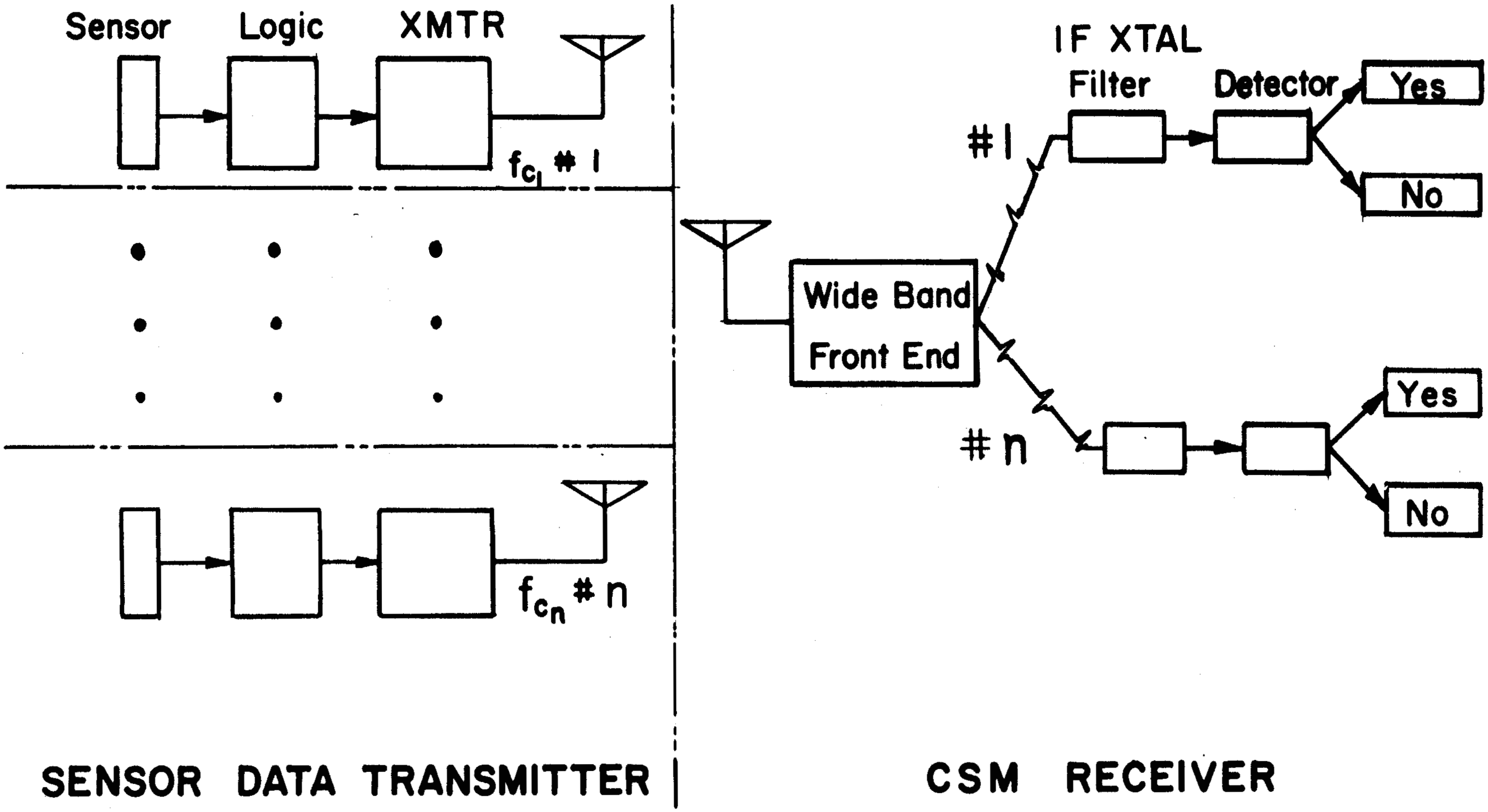
In the time of free fall, the impact limiting bag and the secondary balloons are inflated preparatory to impact with the lunar surface.

On impact with the lunar surface, the inflated system dissipates the impact energy by distortion of the bag and impact surface and by subsequent rolling and sliding friction actions.

On coming to rest in a preferred orientation, the actual test function is initiated on command of the motion sensor system.

The sensor ring nearest the lunar surface is dropped to the surface. The upper penetrometer propulsion cap is detonated driving the penetrometer element down through the sensor ring into the lunar surface.

The threshold condition of penetration is sensed and a GO or NO-GO decision results.



TYPICAL DATA LINK SYSTEM

Figure 3

The resultant decision is then communicated by radio to the orbiting command service module before it passes over the visual horizon.

The transmitter continues to operate on the prescribed intermittent duty cycle for approximately ten hours or five orbit periods subsequent to the first transmission.

The entire sample of replies from the group of landed LSPS systems is displayed to the command/service module crew and a decision formed regarding the safety of the tested surface site.

F. Recommended System Concept Specifications

1. Size

a. Stowed

The stowed system will be within a container approximately six inches in diameter and 12 inches in length with the overall system, including container, weighing approximately ten earth pounds.

b. System Dimensions - Deployed

The inflated bag will be approximately 75 inches on its major diameter and 36 inches on its minor diameter. The impact weight of the system will be approximately 9-pounds earth.

2. Communication System

Each LSPS transmitter will have a carrier frequency in the vicinity of 300 megacycles per second and will provide a radiated modulated RF power of approximately 1 watt.

The entire LSPS electrical system will consume approximately 4 watts of power with the transmitter running and will be provided with sufficient battery capacity for one hour of continuous or ten hours of intermittent transmission.

Communication range of the system will be to the visual horizon or approximately 460 statute miles with an operating signal to noise ratio of 10 decibels.

3. Penetrometer

The penetrometer element proper will have a base diameter of 0.75 inches; an overall length of approximately 12 inches; and a weight of approximately 1.3 pounds earth. The shank of the penetrometer will be approximately 5/8 inch diameter.

A penetration of 10 inches of the penetrating element will be used as the criteria for safe LEM penetration threshold.

G. Models and Mockups

1. Bag Model

Shown in Figure 4a is a full size model of the inflatable bag and its container to demonstrate the size, the inflation characteristics, and stowability of the recommended design.

2. Function Test Model

Figure 4b shows a model made to demonstrate the feasibility of the recommended penetrometer slug propulsion and sensing concept. The superstructure shown contains a penetrometer rod and a single propulsion cap. A fully operable sensor ring is also mounted in a deployment mechanism. A logic breadboard is included to show the GO/NO-GO action.

3. Assembly Mockup

Figure 4c shows a dummy assembly illustrating the major components making up the core assembly of the LSPS. Its body represents the strong laminated core of the balloon surrounded by the helical tank and occupied internally with the penetrometer assembly, electronic modules and batteries.

4. Motion Sensor

To demonstrate the practicality of the motion sensing function a unit was constructed and operated performing a motion cessation decision based on detecting no accelerations during a 30 second interval coupled with a preferred orientation relative to the local vertical.

5. Dimensional Mockups

Ten cylinders were constructed to the recommended dimension of six inches diameter and 12 inches length and were marked with major operating features of the stowed system. These units were furnished to aid in studying mockups of the overall LSP configuration.

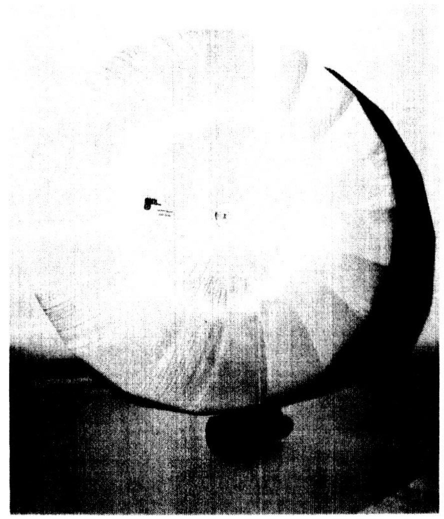


FIGURE 4a INFLATED BAG AND ASSEMBLY

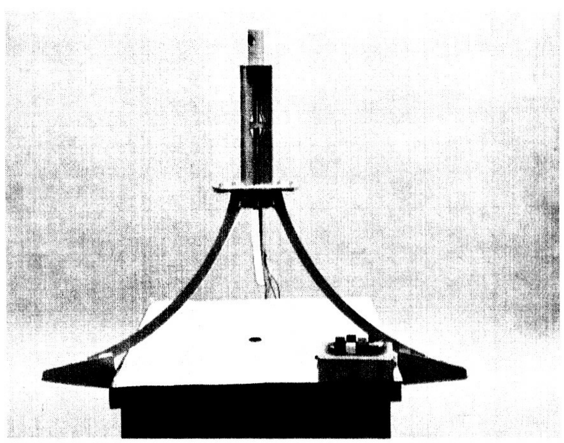


FIGURE 4b FUNCTIONAL TEST MODEL

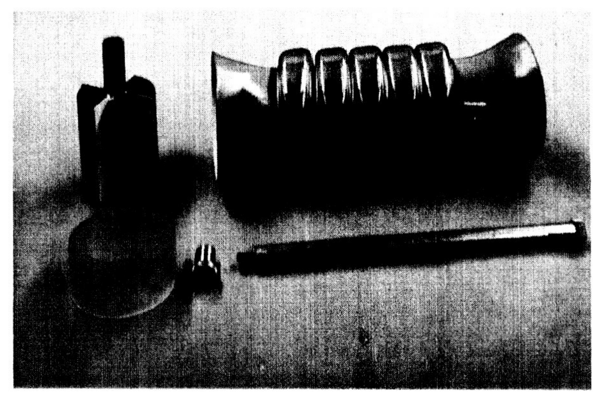


FIGURE 4c CORE ASSEMBLY MOCKUP

Figure 4

VI. STUDY LIMITATIONS

The prediction of confidence level of scaling relation between a small penetrometer element and the LEM pad is limited by lack of detailed knowledge of the nature of the lunar surface material. Soil models are possible, even though their occurrence is felt to be unlikely, which would degrade the reliability of scaling in the recommended measurement configuration. An example of this situation would be soil containing rubble of the proper size where it would have little effect on the large LEM pad but relatively large effect on a penetrating element. The likelihood of such a situation arising is essentially a problem in the statistical distribution expected of such foreign objects in lunar material. The use of a number of LSPS units obviously mitigates the undesirable effects possible in such a situation. The statistical variation of replies in itself would indicate that this was the situation.

Without the availability of large vacuum testing facilities it is difficult to predict the dynamic characteristics of impact of the recommended inflated bag as well as its resistance to damage by penetrating or abrasive actions following impact. A number of approaches and materials have been found to be available to mitigate such effects if they prove to be necessary.

Beyond these limitations however, it is felt that the study went sufficiently far to demonstrate the degree of reliability of the recommended measurement action with regard to its correlation to the action of LEM landing pad. It is also felt that the conceptual design was performed in sufficient detail together with the models described to demonstrate the feasibility and practicality of the overall system configuration.

VII. IMPLICATIONS FOR RESEARCH

The major areas requiring further illumination by analysis and particularly by experiment, were the following:

There is a need for determining more accurately the actual coefficient of restitution and dynamic action of the inflated bag immediately following impact. A set of experiments should be performed within a vacuum facility realistically representing the dynamic forces and environment in which the motion would take place. The results of properly designed experiments in this area would then indicate whether or not the system has sufficiently short settling time as presently recommended, or whether some known techniques must be applied to deliberately shorten the settling time of the system.

The likely resistance to abrasion and performance, although seemingly quite promising for the materials selected, should be more thoroughly known by experiment. These experiments could be combined with the motion tests recommended above. Results of such tests will be helpful in indicating whether or not additional abrasion resistance should be incorporated with the selected materials and of course resulting in accompanying weight penalties.

VIII. SUGGESTED ADDITIONAL EFFORT

The results of the LSPS system have demonstrated that there is a feasible measurement technique for performing a GO/NO-GO assessment of the acceptability of a site for LEM landing. The study has also established a feasible system concept for delivering this system to the lunar surface and performing said measurements.

Thus it is felt that sufficient information and conceptual description exists to allow initiation of a prototype design. This prototype design would encompass the following areas.

1. Delivery System

A bag and core design capable of withstanding a predicted impact stress should be designed and tested together with the inflatant tank and valving provisions required for full operation. Inflation and impact tests should be made in a vacuum to verify the basic design.

2. Communication System

The transmitter, logic, modulator, and power control circuits should be breadboarded to establish the actual power efficiency of the transmitter and its power requirements. A receiver should be breadboarded to verify specifications on filter selectivity and stability designs. Actual communication range tests should be performed.

3. Penetrometer System

Penetrometer element design together with the required magnets and propulsion caps should be constructed, fabricated, and test fired to establish confidence levels in the velocity dispersion of the propulsion system. Included in these tests should be operation of the actual sensor rings and logic circuits.

4. Control System

A breadboard of the control system and the required cartridge actuating elements, arming provisions, and necessary time delays should be constructed and tested of components similar to those acceptable in a flyable model. The breadboard should then be tested for functional integrity and reliability of operation.

5. Packaging and System Integration

Packing configuration, shroud design, and simulated jettison deployment and inflation should be designed in detail and experimentally verified. All functional and physical interfaces with the LSP vehicle should be identified and incorporated into the LSPS design.

6. System Tests

Tests should be performed of entire system operation in a vacuum environment to demonstrate the functional acceptability of the design concept.